

RECENT RESULTS ON TOP PHYSICS AT ATLAS

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During the 2010 pp run of the Large Hadron Collider at $\sqrt{s} = 7$ TeV, a substantial data sample of high p_T triggers, 35 pb^{-1} , has been collected by the ATLAS detector, corresponding to about 2,500 produced top-quark pair events containing at least one lepton (e or μ) in the final state. Measurements of the top-quark pair production cross-section, the top mass, the W helicity fractions in top-quark decays and studies of single-top quark production and top-quark pair production with anomalous missing transverse energy are presented.

1 Introduction

Top-quark measurements are of central importance to the LHC physics programme. The production of top-quark pairs in pp collisions is a process which is situated at the boundary between the Standard Model (SM) and what might lie beyond it. Within the SM, top quarks are predicted to almost always decay to a W -boson and a b -quark. The decay topologies are determined by the decays of the W -boson. In pair-produced top-quarks the single-lepton and dilepton modes, with branching ratios of 37.9% and 6.5% respectively, give rise to final states with one or two leptons (electrons or muons), missing transverse energy (E_T^{miss}) and jets, some with b -flavour.

2 Top quark pair production cross-section $\sigma_{t\bar{t}}$

The measurement of $\sigma_{t\bar{t}}$ is a milestone for early LHC physics. Within the SM the $t\bar{t}$ production cross-section at $\sqrt{s} = 7$ TeV is calculated to be $165_{-16}^{+11} \text{ pb}$ at approximate NNLO¹ for a top-quark mass of 172.5 GeV. A precise determination of $\sigma_{t\bar{t}}$ tests these perturbative QCD predictions. First measurements of $\sigma_{t\bar{t}}$ at the LHC have been reported by ATLAS² and CMS³ with 3 pb^{-1} . Here, approximately ten times more data have been analysed.

2.1 Dilepton channel

The cross-section in the dilepton channel is extracted with a cut-and-count method⁴. Candidate events are selected by requiring two opposite-signed high- p_T leptons in the ee , $\mu\mu$ and $e\mu$ topologies, and at least two jets. The background contribution from Drell-Yan production is suppressed by requiring for same-flavour events large E_T^{miss} and for $e\mu$ events large H_T , the scalar sum of jet and lepton transverse energies. Remaining Drell-Yan events and background from fake leptons are estimated with data-driven methods. Across the three channels 105 events are selected with an expected S/B ratio of 3.6. The cross-section is extracted with a profile likeli-

hood technique, with a simultaneous fit to the three channels and taking into account systematic uncertainties. This results in $\sigma_{t\bar{t}} = 174 \pm 23$ (stat.) $^{+19}_{-17}$ (syst.) ± 7 (lumi.) pb.

Additional studies are performed to corroborate this measurement: a technique that normalizes the $t\bar{t}$ signal yield to the measured rate of Z -boson decays; a two-dimensional template shape fit using the E_T^{miss} vs N_{jets} variables to simultaneously measure the production cross-sections of the $t\bar{t}$, WW and $Z \rightarrow \tau\tau$ final states; and a cross-section measurement that requires at least one b -tagged jet and a looser kinematic selection to optimize the S/B ratio. All measurements are in good agreement with each other.

2.2 Single-lepton channel

Two complementary measurements have been performed in the single-lepton channel. In the first measurement no explicit identification of secondary vertices inside jets (b -tagging) is performed⁵. The main background consists of W +jet events and QCD multi-jet events, where one jet mimics a reconstructed lepton. The latter are particularly difficult to simulate correctly and are thus estimated using data-driven techniques. Selected events are classified according to lepton flavour (2009 candidate events observed in μ +jets and 1181 in e +jets) and according to jet multiplicity: exactly 3 jets or ≥ 4 jets. Three variables that exploit the different kinematic behaviour of $t\bar{t}$ and the W +jets background events are identified and used in a multivariate likelihood fit to extract $\sigma_{t\bar{t}} = 171 \pm 17$ (stat.) $^{+20}_{-17}$ (syst.) ± 6 (lumi.) pb. The main systematic uncertainties are due to the limited knowledge of the jet energy scale and reconstruction efficiency as well as the amount of initial and final state radiation.

A second method exploits the b -tagging capabilities, albeit making use of a simple and robust tagging algorithm with a modest rejection factor⁶. A multivariate likelihood discriminant is constructed using template distributions of four variables, among which the average of the weights of the most significant b -tags. Here, data are further split with an additional jet-bin (3, 4 or ≥ 5 jets). A profile likelihood technique is used to extract $\sigma_{t\bar{t}}$ and constrain the systematic effects from data. The result is $\sigma_{t\bar{t}} = 186 \pm 10$ (stat.) $^{+21}_{-20}$ (syst.) ± 6 (lumi.)pb, where the systematic uncertainties are dominated by the uncertainties in the b -tagging algorithm calibration from data and the heavy flavour fraction in W +jets events. Cross-check measurements are performed with kinematic fits of the reconstructed top mass and cut-and-count methods and are found to be in good agreement with this result.

2.3 Combination

The most precise cross-section measurements in the dilepton and single-lepton channels are combined, taking into account correlated systematic uncertainties⁷. The result has a total uncertainty of 10%, $\sigma_{t\bar{t}} = 180 \pm 9$ (stat.) ± 15 (syst.) ± 6 (lumi.) pb, and is in excellent agreement with the SM prediction as shown in Figure 1 (right).

3 Single-top production

The observation of electroweak production of single-top quarks has been reported by the CDF and D0 collaborations in 2009. This final state provides a direct probe of the W - t - b coupling and is sensitive to many models of new physics. The measurement of the production cross-section determines the magnitude of the quark mixing matrix element V_{tb} without assumptions on the number of quark generations. With the available data sample searches for single-top quark production in the t - and Wt -channels are performed⁸.

The t -channel search is based on the selection of events with exactly one identified lepton, jets and E_T^{miss} . In a cut-based analysis a reconstructed three-jet invariant mass compatible with $m_{t\text{top}}$ is required, as well as the leading jet to be in the forward direction. This selects 32

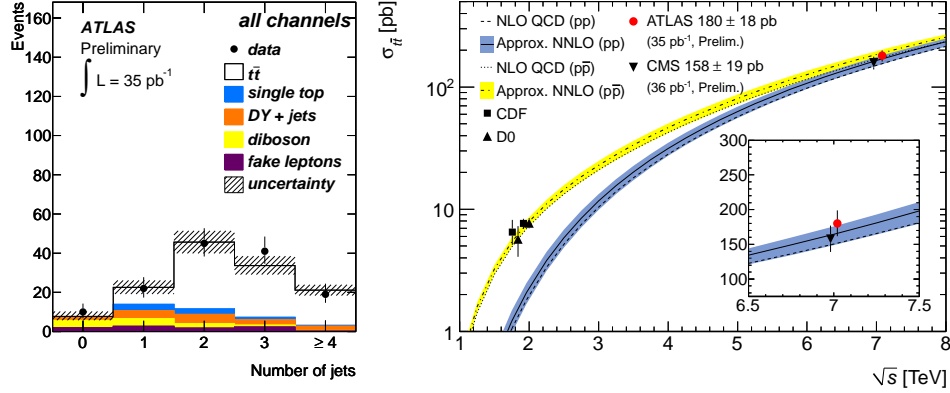


Figure 1: Selected dilepton events superimposed on expectations from simulation and data-driven estimations (left). Cross-section measurements at Tevatron and LHC compared to approximate NNLO predictions (right).

candidate events. Using data-driven methods to estimate the QCD and W +jets backgrounds, a production cross-section of $\sigma_t = 53^{+46}_{-36}$ pb is measured, which translates to an upper limit of 162 pb at 95% confidence level. A likelihood function approach is also used to cross-check the result. Both results are consistent with the SM expectation of 66 pb.

The Wt -channel analysis is based on the selection of events with either one or two leptons, jets and E_T^{miss} . The expected SM cross-section for this single-top process is 15 pb. A 95% confidence level limit is set on the Wt -channel production cross section of $\sigma_{Wt} < 158$ pb. In the dilepton channel, the $t\bar{t}$ background is estimated from data, by considering the one-jet bin as a control region.

4 Top quark properties

4.1 Mass

The top-quark mass, a fundamental parameter of the SM, is a source of large contributions to electroweak radiative corrections and, in conjunction with precision electroweak measurements, can be used to derive constraints on the Higgs boson mass or heavy particles predicted in SM extensions. The current world average is $m_{\text{top}} = 173.3 \pm 1.1$ GeV.

The main systematic on the determination of the top-quark mass is the uncertainty in the jet energy scale (JES). Three complementary template analyses have been developed⁹ that address the uncertainty due to the JES in different ways: a 2D analysis that simultaneously determines m_{top} and a global jet energy scale factor between data and predictions; a 1D analysis exploiting a kinematical likelihood fit to all decay products of the $t\bar{t}$ system; a 1D analysis which is based on the ratio between the per-event reconstructed invariant mass of the top-quark and the mass of the W -boson associated to the hadronically decaying top-quark candidate. The latter method yields a top-quark mass measurement of $m_{\text{top}} = 169.3 \pm 4.0 \pm 4.9$ GeV.

4.2 W -boson polarisation in top-quark decays

The polarisation states of the W -bosons that emerge from top-quark decays are well defined in the SM, due to the $V - A$ structure of the charged current weak interactions. These can be extracted from the angular distributions of the decay products in $t \rightarrow bW \rightarrow b\ell\nu_\ell$.

In a first measurement¹⁰, templates of the $\cos\theta^*$ distribution are built from simulation and fitted to selected events with a single charged lepton, E_T^{miss} and at least four jets, where at least one of them is b -tagged. Here θ^* is the angle between the direction of the lepton and the reversed

momentum direction of the b quark from the top-quark decay, both boosted into the W -boson rest frame. Events are reconstructed in the single-lepton channel with a kinematic fit method. Assuming $F_R = 0$ helicity fractions $F_0 = 0.59 \pm 0.12$ and $F_L = 0.41 \pm 0.12$ are extracted. A second measurement is based on angular asymmetries constructed from the $\cos \theta^*$ variable, the events are reconstructed with a χ^2 fitting technique and an iterative procedure is applied to correct for detector and reconstruction effects in order to recover the undistorted distribution on parton level. The helicity fractions are measured to be $F_0 = 0.65 \pm 0.15$, $F_L = 0.36 \pm 0.10$ and $F_R = -0.01 \pm 0.07$. Both results are in good agreement with the SM prediction and are used to place limits on anomalous couplings V_R , g_L and g_R that arise in new physics models.

4.3 Search for anomalous E_T^{miss} in $t\bar{t}$ events

A search for anomalous E_T^{miss} in the single-lepton $t\bar{t}$ final state has been performed¹¹. Such a phenomenon can arise from a number of extensions of the SM, but the focus here is on a search for a pair-produced exotic top partner T with mass $m(T)$, that decays to a top-quark and a long lived neutral scalar particle A_0 . The final state for such a model is identical to $t\bar{t}$, but with a large amount of E_T^{miss} from the undetected A_0 's. First limits from the LHC on the mass of such a particle are established, excluding $m(T) < 300$ GeV for $m(A_0) = 10$ GeV and $m(T) < 275$ GeV for $m(A_0) = 50$ GeV with 95% confidence.

5 Conclusion and Outlook

With the first 35 pb⁻¹ of pp collision data collected at $\sqrt{s} = 7$ TeV in 2010, a suite of top-quark measurements has been presented by ATLAS. Some of these measurements have uncertainties that are already competitive with uncertainties of theoretical predictions. For instance, $\sigma_{t\bar{t}}$ is now measured with an accuracy at the level of 10%. With the increase of the dataset by two orders of magnitude the whole spectrum of top physics can be explored at LHC.

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